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# Respiratory changes due to extreme cold in the Arctic environment

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**Abstract.** Effects of acute exposure and acclimatisation to cold stress on respiratory functions were investigated in healthy tropical Indian men ($n = 10$). Initial baseline recordings were carried out at Delhi and thereafter serially thrice at the arctic region and once on return to Delhi. For comparison the respiratory functions were also evaluated on Russian migrants (RM; $n = 7$) and Russian natives (RN; $n = 6$). The respiratory functions were evaluated using standard methodology on a Vitalograph. In Indians, there was an initial decrease in lung vital capacity (VC), forced vital capacity (FVC), forced expiratory volume 1st s (FEV1), peak expiratory flow rate (PEFR) and maximum voluntary ventilation (MVV) on acute exposure to cold stress, followed by gradual recovery during acclimatisation for 4 weeks and a further significant improvement after 9 weeks of stay at the arctic region. On return to India all the parameters reached near baseline values except for MVV which remained slightly elevated. RM and RN showed similar respiratory functions at the beginning of acute cold exposure at the arctic zone. RN showed an improvement after 10 weeks of stay whereas RM did not show much change. The respiratory responses during acute cold exposure are similar to those of initial altitude responses.

**Key words:** Respiratory functions – Arctic environment – Acute cold stress – Cold acclimatisation

## Introduction

Men living in the northern region of the globe are normally exposed to a cold environment, and with the advent of Arctic and Antarctic expeditions more and more people are exposed to extreme cold environments. With the enormous increase in global travel by air, sea and rail, the problem of transmigration from the tropics to cold regions is drawing the attention of scientists worldwide.

Acute induction to an extreme cold environment results in the modulation of respiratory functions. Earlier experiments in cold have been conducted by deliberately exposing subjects in a cold chamber (Davis 1961) or subjects were assessed before and after an outdoor experience of some duration (Carlson and Hseih 1965). Biryukov (1960) had emphasised that the mechanism of interaction of an organism with the environment can best be understood under natural conditions.

Hence, the progressive changes in lung functions during acute induction and acclimatisation were evaluated in men indigenous to the tropics when they were exposed to the natural arctic environment. The basic hypothesis of the present study was that subjects born and brought up in a tropical environment might respond differently to a regimen of daily cold exposure and may not show the same degree of acclimatisation found in temperate/arctic subjects. This paper deals with progressive changes in the respiratory functions of Indians during a stay at the arctic region for 10 weeks, and compares their responses with those of Russian migrants ($n = 7$) from Moscow and Russian natives ($n = 6$) residing at the arctic region.

## Materials and methods

Experiments were conducted on 10 Indian subjects (IS) representing all regions of India, 7 Russian migrants (RM) and 6 Russian natives (RN) in the age group of 20–40 years. Subjects were maintained on a diet supplying about 4000 kcal and controlled physical activity schedule throughout the period of study. The first recordings on the Indian subjects were done at Delhi (29° N 77° E) during the month of November and thereafter three serial recordings were carried out at the arctic region of Russia and one on return to Delhi.

The subjects were rested in a room maintained at $21 \pm 1°$ C for 15 min before the following respiratory functions were recorded: static lung volume of vital capacity (VC); dynamic lung volume of forced vital capacity (FVC); forced expiratory volume 1st s (FEV1); peak expiratory flow rate (PEFR) and maximum voluntary ventilation (MVV); and indices of forced expiratory flow (FEF), i.e. FEF 25%, FEF 50% and FEF 75% obtained from the maximal expiratory flow volume curve recorded on a vitalograph (UK) using standard methodology.

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Vital capacity (VC) is defined as the maximum volume that can be expired after maximal inspiration. It depends on the stature, strength of respiratory muscles and pulmonary compliance. Following maximal inspiration, the entire vital capacity volume expelled as rapidly and as completely as possible is termed the forced vital capacity (FVC). Forced expiratory volume in 1st s (FEV1) is the volume of forced expiratory vital capacity expired during the 1st s. Peak expiratory flow rate (PEFR) is the maximal expiratory flow rate that can be sustained for a period of 10 ms. Maximum voluntary ventilation (MVV) is the maximal volume of gas that can be ventilated by motivated ventilatory effort during a given number of seconds, expressed in l/min.

The tests of ventilatory capacity are a good measure of the overall function of the lung. The ventilatory capacity is dependant on the lung or chest wall elasticity, increased airway resistance leading to the obstruction and strength of respiratory muscles (Slonim and Hamilton 1976). FEV1, PEFR and FEF 25% are altered with changes in resistance in the larger airways while FEF 50% and FEF 75% are affected by changes in resistance in smaller airways. Respiratory muscle fatigue plays a role in changing FVC and MVV.

After completion of the baseline studies at Delhi, the Indian subjects and scientists were airlifted to the arctic region of Russia (70° N 38° E). Russian migrants were also airlifted to the arctic region from Moscow during the same period. All the three groups of subjects were housed in temporary wooden huts for 10 weeks room temperature maintained at 15–20° C. Further respiratory function studies were conducted during the 1st, 5th and 9th weeks of the stay at the arctic region in all the three groups of subjects following 15 min rest in the laboratory, which was maintained at 20 ± 2° C. All the volunteers were exposed to the same environment; their caloric intake was nearly identical (about 4000 kcal) and all were engaged in a fixed daily schedule of physical activity. The schedule comprised snow clearing, fetching water from the frozen river nearby, marching on snow terrain and physical exercise; this constituted some of the routine activities that provided ample cold exposure in the natural cold environment. The ambient environmental temperature during the period of study ranged from −8.5 to −37° C.

Indian subjects were airlifted back to Delhi after 10 weeks of sojourn at the arctic region. Within a week of their return to Delhi, the respiratory function tests were repeated. All recordings were carried out in the morning, about 2 h after breakfast, in similar laboratory conditions, using the same equipment and by the same observer. The data were analysed using analysis of variance (ANOVA). Comparisons were made of the data of Indian subjects at Delhi with their arctic responses. Intergroup comparisons were also made on the data among the three groups of subjects studied at the arctic environment.

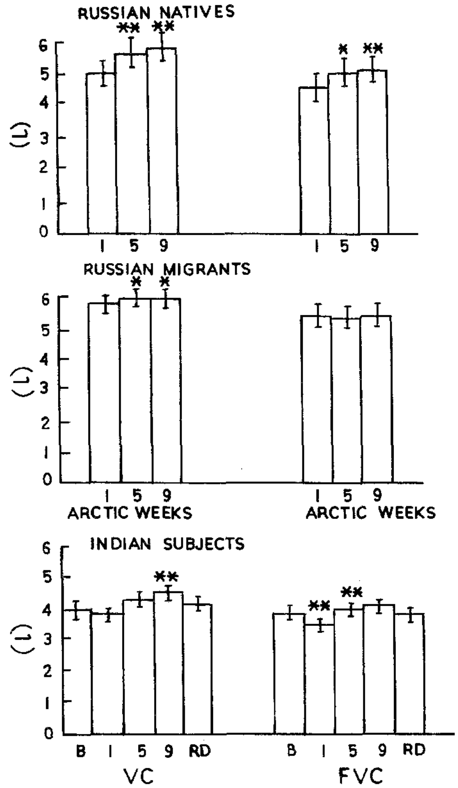


**Fig. 1.** Changes in lung vital capacity (VC) and forced vital capacity (FVC) during acclimatisation to cold in the arctic environment. Values are mean ± SEM. Statistical significance of initial with arctic values (1, 5 and 9 weeks) in Indian subjects; comparison of Arctic 1 with 5 and 9 in Russian migrants and Russian natives: * $P<0.05$, ** $P<0.01$. B, Baseline data at Delhi; RD, return to Delhi

## Results

Russian volunteers, both natives and migrants were well developed in all physical characteristics compared to the tropical Indian subjects (Table 1). In the Indian subjects, VC initially (1st week) showed a tendency to decrease but thereafter improved reaching a peak value by the 9th week ($P<0.01$; Fig. 1). The Russian migrants and Russian natives revealed a higher initial VC value compared to the baseline values of IS ($P<0.01$). Intergroup differences between the Russian volunteers (RM and RN) were not significant; during the study both of the Russian groups showed an improvement in VC during their stay at the arctic environment ($P<0.01$).

FVC, FEV1, PEFR and MVV followed a similar trend in IS (Fig. 2). On acute exposure to cold, a significant reduction was observed in all the parameters ($P<0.05$), followed by a significant improvement by 9 weeks. The Russian migrants revealed a higher value of FVC, FEV1, PEFR and MVV whereas the Russian natives showed an increased value of MVV ($P<0.05$) and non-significant decrease in PEFR compared to the baseline values at Delhi. The intergroup difference in RM and RN during the 1st week at the arctic was significant ($P<0.01$).

A significant improvement was observed in the Indi-

**Table 1.** Physical characteristics of subjects (mean ± SD)

| Subjects | Age (years) | Height (cm) | Weight (kg) | BSA ($m^2$) |
|---|---|---|---|---|
| IS ($n=10$) | 25.0 ± 3.20 | 170.0 ± 5.66 | 61.34 ± 4.92 | 1.71 ± 0.09 |
| RM ($n=7$) | 29.0 ± 7.44 | 174.9 ± 6.54 | 81.09 ± 14.46 | 1.94 ± 0.13 |
| RN ($n=6$) | 31.0 ± 2.96 | 178.0 ± 6.54 | 75.50 ± 15.27 | 1.90 ± 0.14 |

IS, Indian subjects; RM, Russian migrants; RN, Russian natives
Body surface area (BSA) is derived from height and weight nomogram

**Table 2.** Forced expiratory flow rates (FEF 25%, FEF 50%, FEF 75%) of Indian subjects (IS) during acclimatisation at the arctic (1, 5, 9 weeks) compared to Russian migrants (RM) and Russian natives (RN)

| Parameters | | Initial, at Delhi | Arctic | | | Return to Delhi |
|---|---|---|---|---|---|---|
| | | | Week 1 | Week 5 | Week 9 | |
| FEF 25% | IS | 6.22±0.40 | 6.01±0.49 | 6.64±0.53 | 7.10±0.66 | 6.48±0.43 |
| | RM | – | 7.76±0.75 | 7.88±0.92 | 8.57±0.69 | – |
| | RN | – | 6.44±0.44 | 6.93±0.78 | 7.04±0.77** | – |
| FEF 50% | IS | 3.93±0.35 | 3.41±0.23 | 3.86±0.26 | 4.07±0.33 | 3.89±0.34 |
| | RM | – | 5.73±0.65 | 5.14±0.67 | 5.39±0.75 | – |
| | RN | – | 4.34±0.53 | 4.79±0.65* | 4.68±0.67 | – |
| FEF 75% | IS | 1.81±0.18 | 1.53±0.11 | 1.75±0.13 | 1.67±0.18 | 1.61±0.11 |
| | RM | – | 3.17±0.56 | 2.70±0.35 | 2.60±0.39 | – |
| | RN | – | 1.87±0.26 | 2.22±0.32 | 1.99±0.30 | – |

Values are mean±SEM
Statistical significance of comparison of arctic 1st week with 5th and 9th weeks in RM and RN: * $P<0.05$; ** $P<0.01$

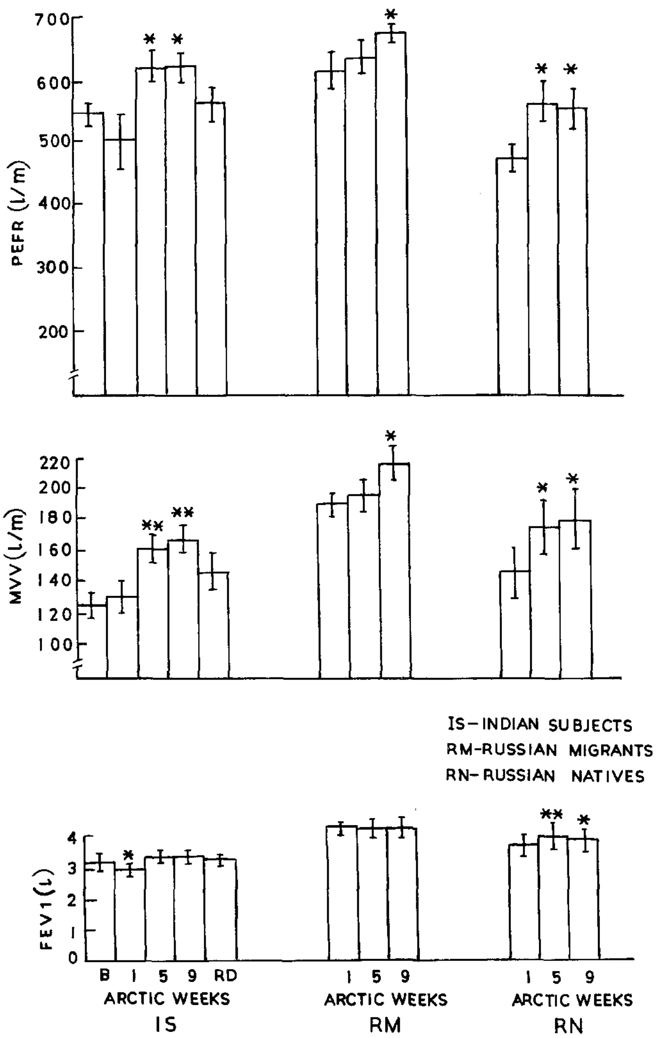


**Fig. 2.** Forced expiratory volume 1st s (FEV1), maximum voluntary ventilation (MVV) and peak expiratory flow rate (PEFR) during 9 weeks of acclimatisation in the arctic environment. Values are mean±SEM. Statistical significance of initial with arctic values (1, 5 and 9 weeks) in Indian subjects (IS); comparison of Arctic 1 with 5 and 9 in Russian migrants (RM) and Russian natives (RN): * $P<0.05$, ** $P<0.01$. B, Baseline data at Delhi; RD, return to Delhi; PEFR, peak expiratory flow rate; MVV, maximum voluntary ventilation; FEV1, forced expiratory volume 1st s

ans and the Russian natives in all four parameters during their stay at the arctic ($P<0.01$); the Russian migrants showed an improvement in PEFR and MVV ($P<0.05$) during acclimatisation (Figs. 1 and 2). Expiratory flow rates did not change significantly on acute exposure to cold in IS during the 1st week and also during acclimatisation in IS and RM (Table 2). RN showed an improvement in FEF 25% and FEF 50%. On return to the tropical environment at Delhi all the respiratory parameters returned to near baseline values.

## Discussion

This study was undertaken to evaluate the respiratory responses evoked on exposure to the acute cold environment in the arctic and thereafter during acclimatisation. The results suggest that cold stress prevailing in the arctic resulted in specific respiratory responses on acute exposure and during 9 weeks of acclimatisation in tropical Indian volunteers.

The respiratory functions recorded were tests of ventilatory capacity. The respiratory parameters of VC and FVC declined immediately on exposure to acute cold. Mehlar and Loke (1981) in their study concluded that a decrease in VC on cold exposure could be due to poor effort, airway obstruction, changes in pulmonary compliance and respiratory muscle fatigue. 'Poor effort' is unlikely to account for the decline in the present study as the subjects were highly motivated and co-operative. A minimal airway obstruction due to engorgement of the nasal mucosa and upper respiratory tract, and the reflex increase in bronchomotor tone led to an increase in airway obstruction (Assoufi et al. 1986; Heaton et al. 1984). Dilatation of the pulmonary capillaries due to acute cold exposure results in pulmonary hypertension. Restrictive changes in the lungs as a sequela to pulmonary hypertension led to a decrease in the compliance of the lungs which in turn resulted in a significant decrease in VC (Landysheva et al. 1980). The role of respiratory muscle fatigue in bringing about an increase in the tonus of muscles of the thoracic cage cannot be ruled out (Hseih et al. 1968). VC and FVC showed an improvement and reached a significantly higher value by the 5th week at the arctic and continued to improve further.

FEV1 as an effort-dependant parameter and a better reproducible test followed a similar trend. The site of action of cold inspired air is most likely the larger airways as the cold inspired air is warmed up on its downward passage and does not come in contact with the peripheral airways (Leblanc 1956). Stimulation of stretch receptors by cold reflexly induces bronchoconstriction leading to an increase in airway resistance and this is mediated by the vagus nerve (Widdicombe 1974; Nadel and Widdicombe 1962).

The PEFR depends on a number of factors including the strength of expiratory effort, the resistance of the airways and the volume of air displaced. The volume of air displaced in turn depends upon the compliance of the airways and lungs, and the rate of change in pleural pressure with respect to time (Vanden et al. 1973). The initial reduction in PEFR indicates an increase in the resistance of the airways as a result of acute cold exposure. O'hara et al. (1977) reported a decrease in FVC, FEV1, and PEFR when subjects were exposed in cold chambers simulating arctic and sub-arctic conditions, and made to perform the activities of long-range military patrols.

The expiratory flow rate during the later period of the expiratory flow volume curve is largely independent of effort and is a function of elastic recoil pressure, the calibre of the airways and the density of respired gas (Hyatt and Black 1973). Forced expiratory flow rate at 25%, 50% and 75% VC showed an insignificant decrease in all the three groups possibly as a result of an increase in bronchial tone especially in the upper airways.

In the present study the results of ventilatory functions after 5 weeks of acclimatisation were near the baseline values at Delhi. There was a further significant improvement after 9 weeks of stay at the arctic in VC and MVV due to the increase in metabolism (Glickman et al. 1967), incrased muscle power and a relaxation of the upper airways as a function of acclimatisation. The changes in the expiratory flow rates were not significant, being largely independent of muscle power.

The Russian migrants showed better physical conditioning as they were soldiers of the Russian armed forces whereas the Russian natives were relatively sedentary with professional occupations such as doctors or research scientists. The lung volumes were almost similar in both of the groups. The Russian natives showed an improvement in all the respiratory parameters during their stay at the arctic. This could be attributed to the regular exercise schedule during the period of study. The Russian migrants did not show much change except of VC in between trials ($P<0.05$). Russians had better respiratory functions compared to tropical Indians (even after correcting for height). Ethnic differences (Jain and Ramiah 1969), larger body size (Cotes 1975) and better nutrition are some factors responsible for the better respiratory functions observed in Russians.

Selvamurthy et al. (1983) reported an initial decline followed by improvement in the respiratory functions to reach a peak within 10 days of stay at altitude. In the present study, cold per se without any additional effect of altitude led to an improvement in respiratory functions in about 10 weeks of stay in the arctic region. On return to Delhi all the respiratory functions returned to their baseline values except for MVV ($P<0.05$). No permanent changes were observed in the respiratory functions.

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